

4/30/2013

Hydrogen Science & Engineering

Dynamic Materials Testing in Hydrogen Gas at Sandia National Labs

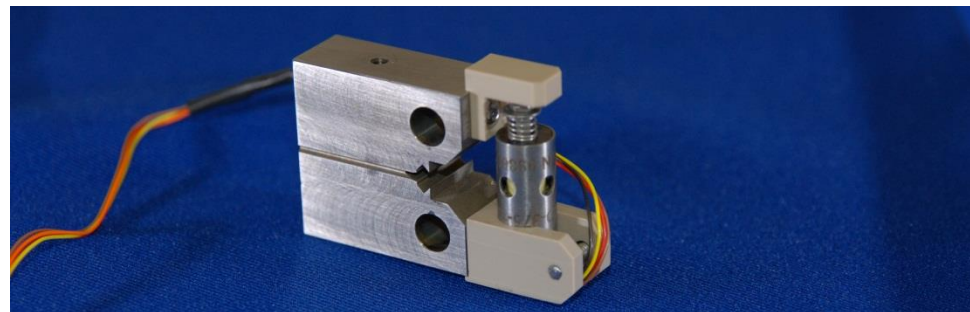
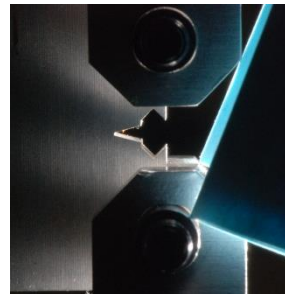
Ken Lee

Brian Somerday and Chris San Marchi



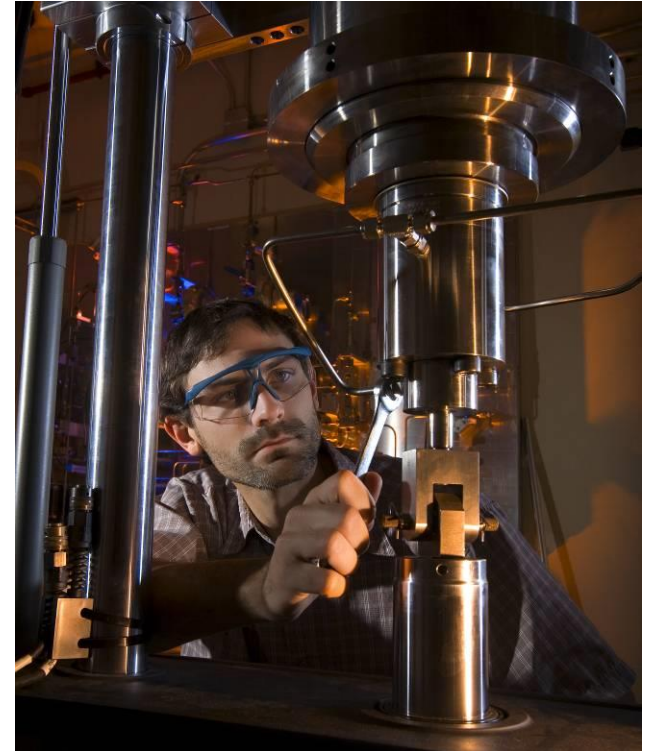
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*Exceptional service
in the national interest*



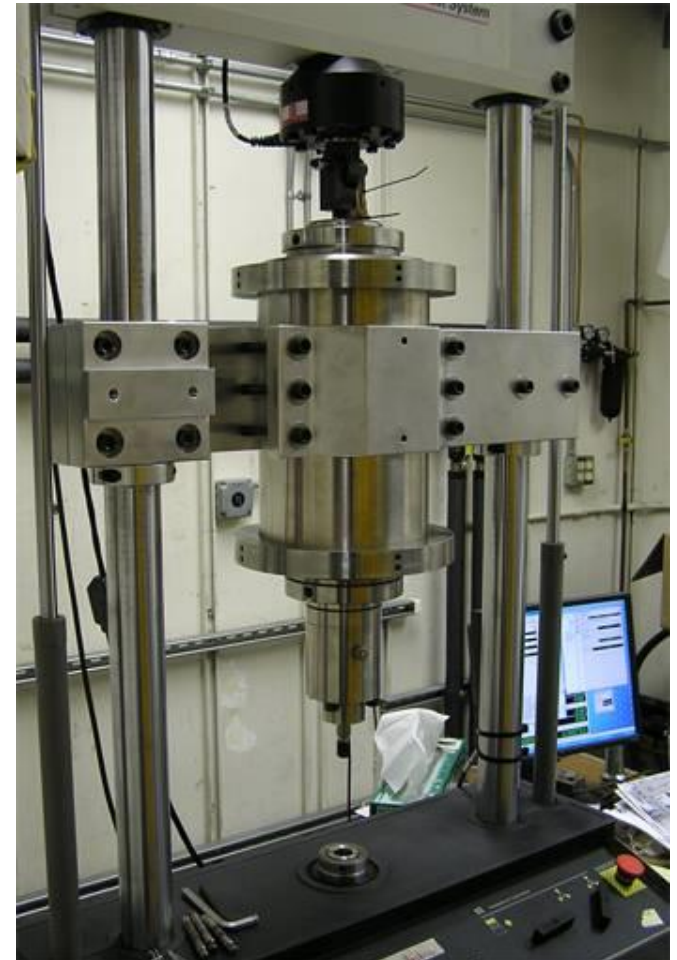
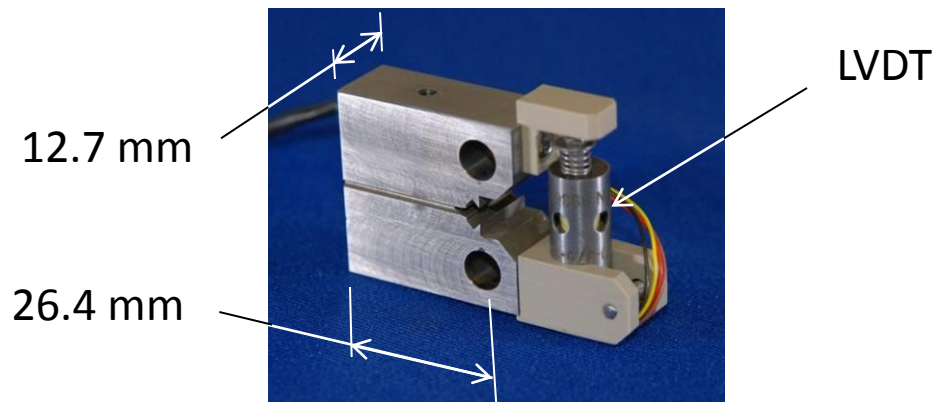
Outline

- Objectives
- Capabilities
- Design concept
- Transducers
- Test capability boundaries
- Gas management
- Safety considerations
- Challenges and successes
- Next generation design

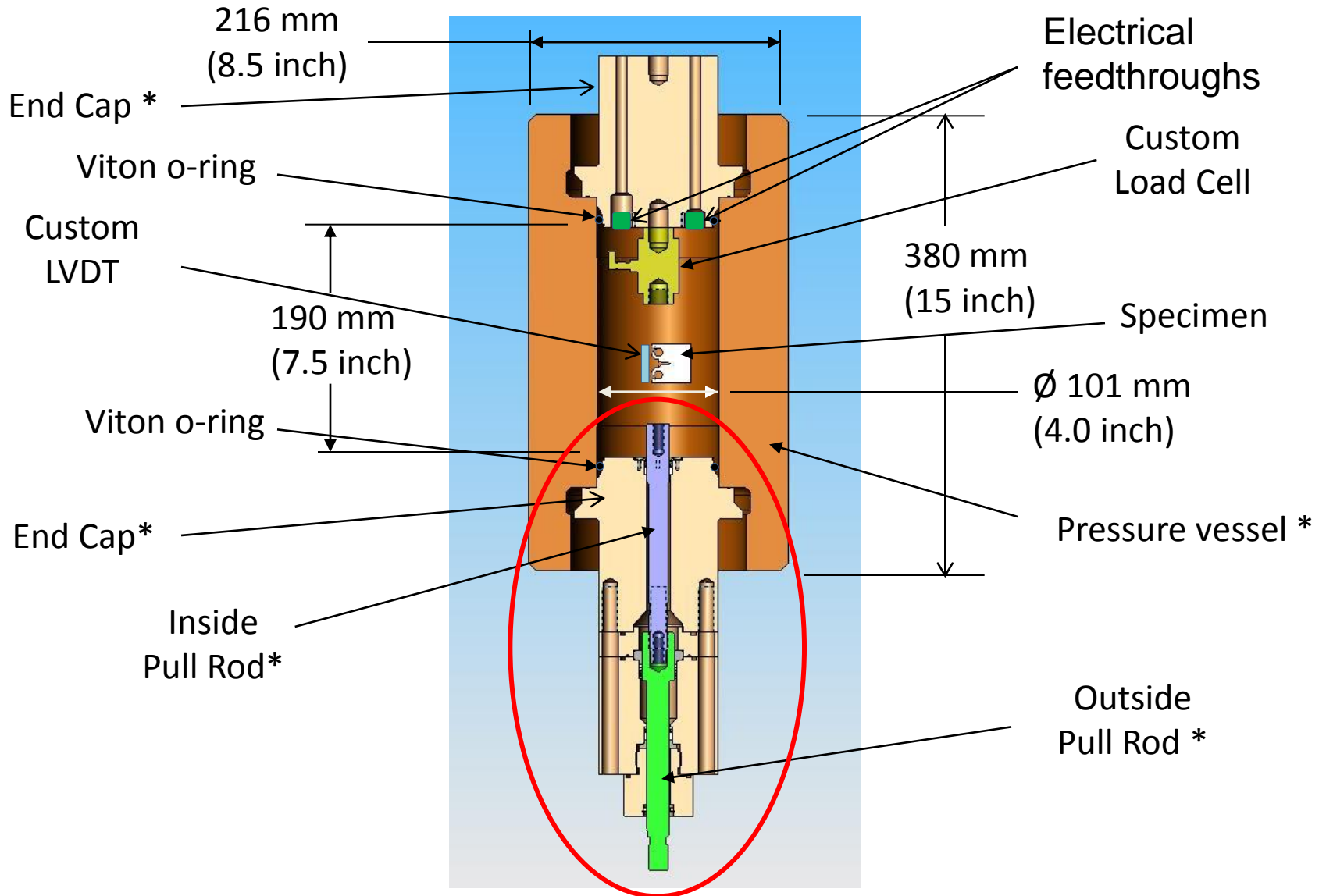


Design objective to developing dynamic test capability

- Pressure = 140 MPa
- Fatigue, fracture, tensile tests
- Pressure vessel with internal transducers
 - Specimen load: strain gage load cell
 - Specimen displacement: LVDT
(linear variable differential transformer)

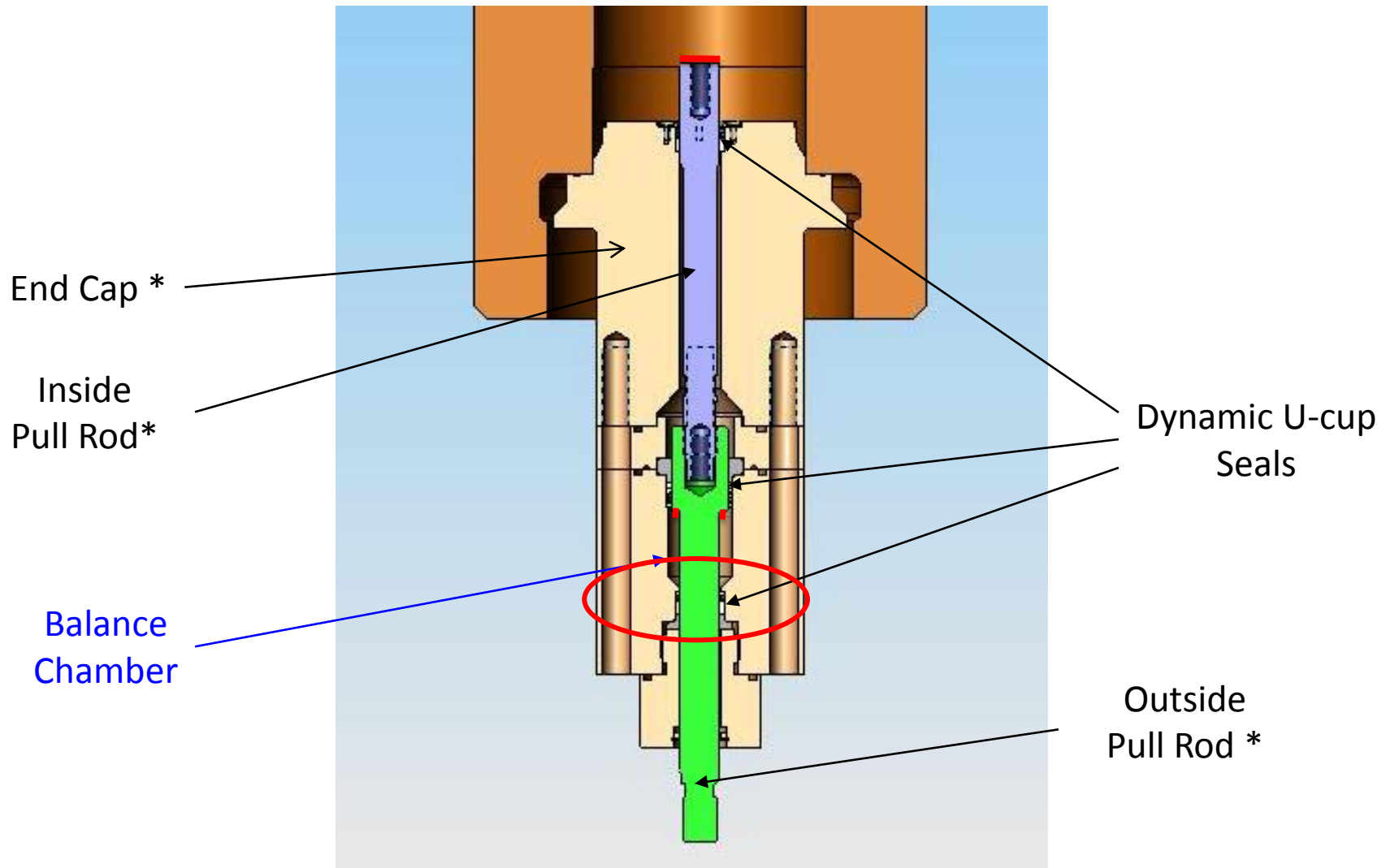


Design concept of pressure vessel



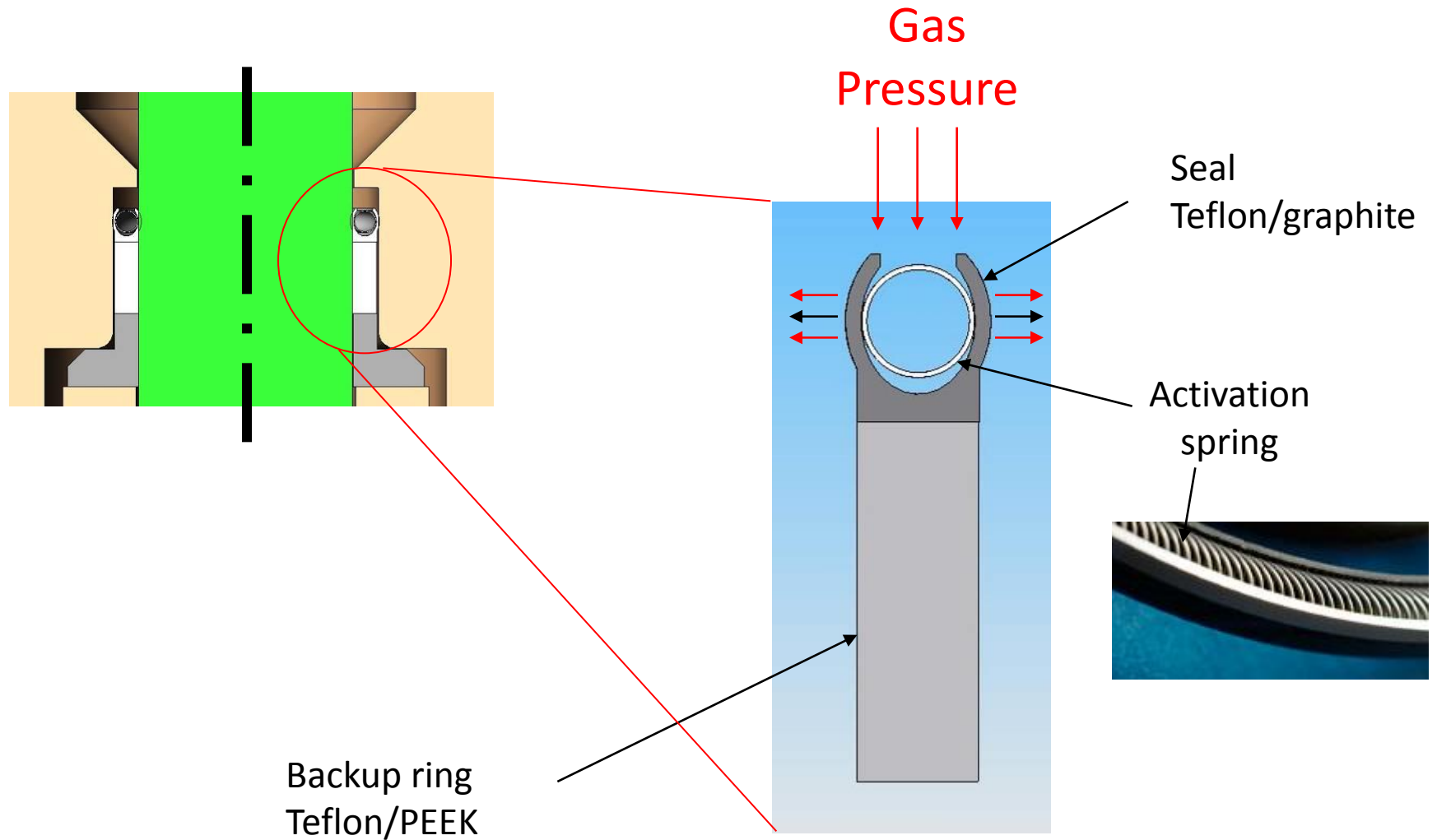
* Material: A286 Precipitation hardened austenitic stainless steel

Design concept of pressure vessel



* Material: A286 Precipitation hardened austenitic stainless steel

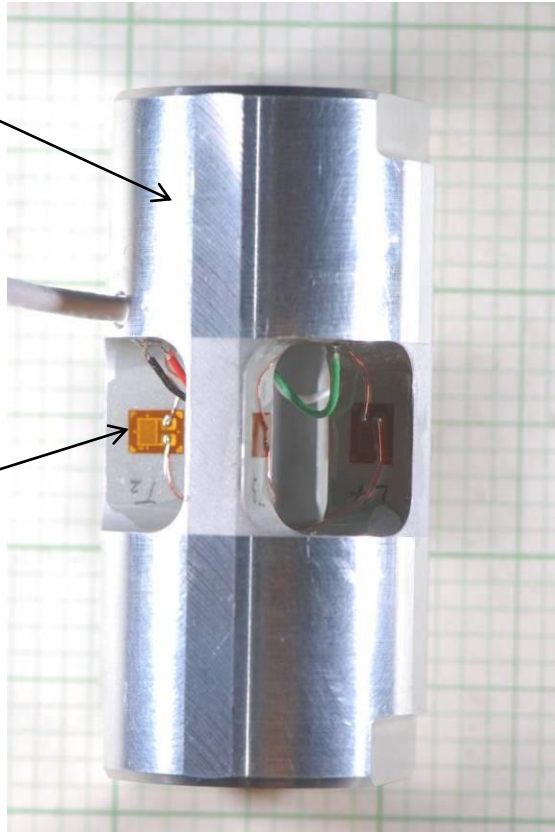
Construction of dynamic U-cup seals



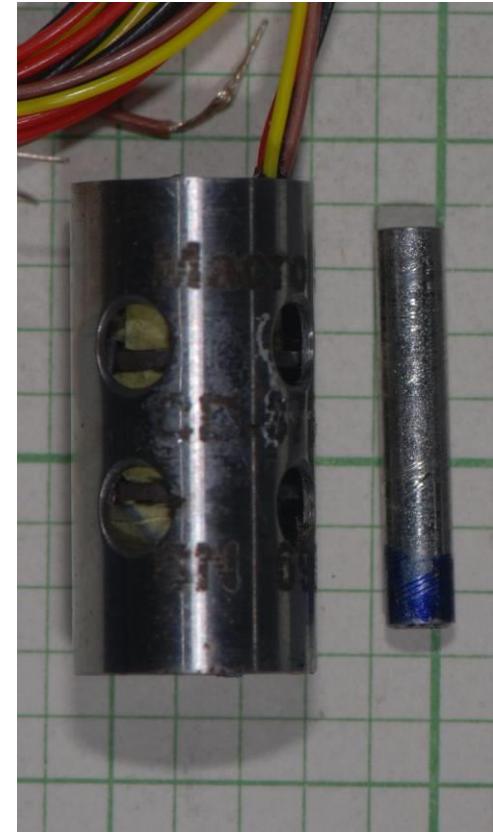
In situ transducers

7075-T6
aluminum

Karma alloy
SK-13-150-350
Full bridge
8 strain gages

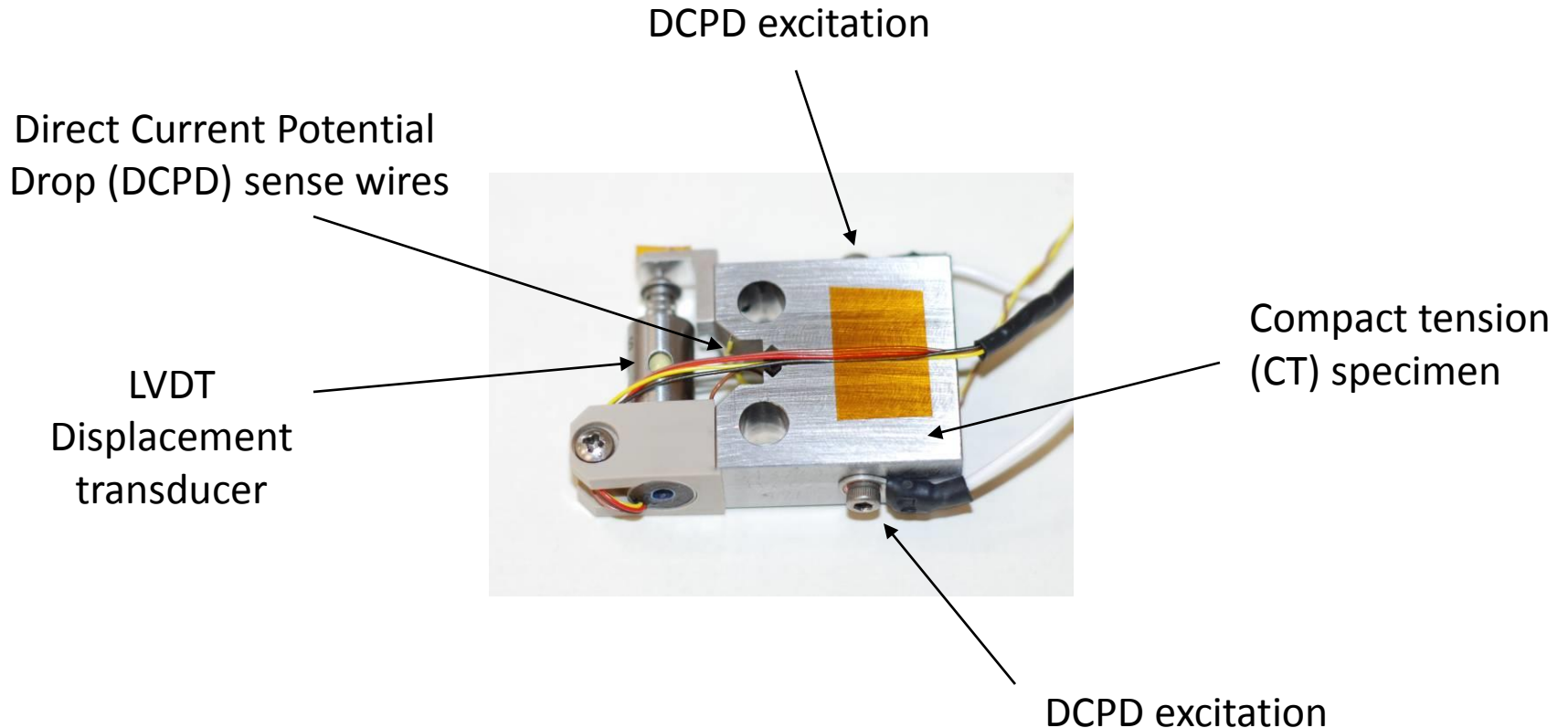


Strain gaged
Load cell



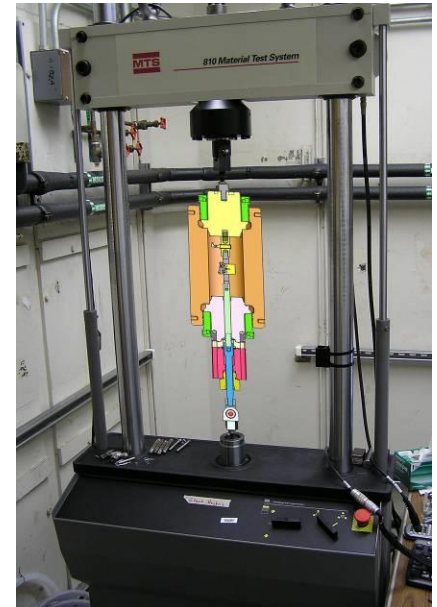
Vented
LVDT

CT specimen assembly with LVDT and DCPD



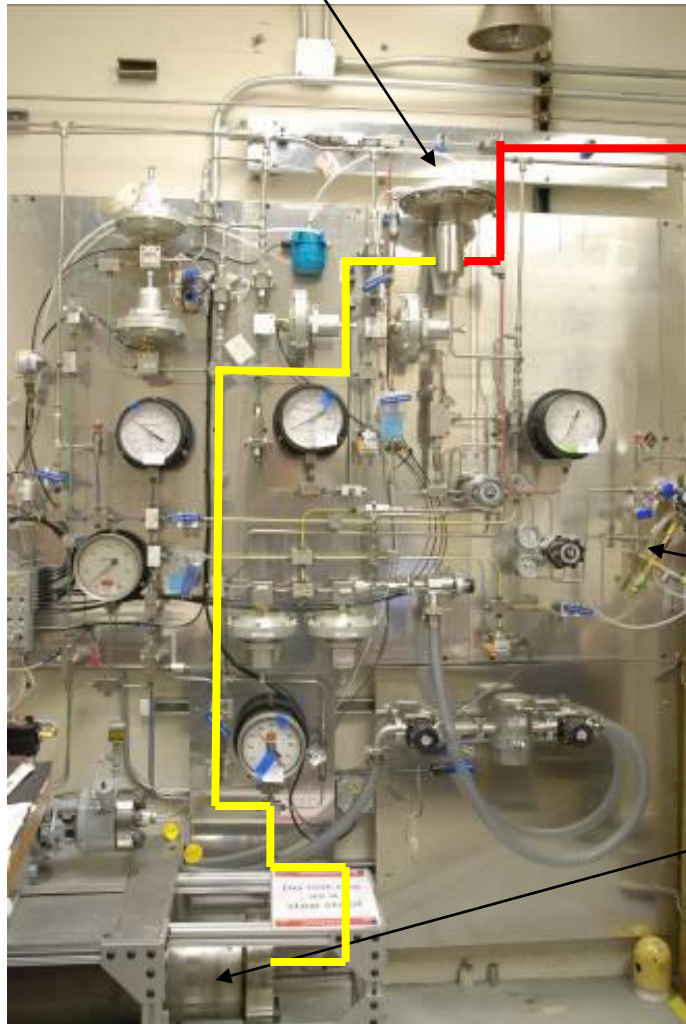
Test capability boundaries

	Tensile/fracture	Fatigue
Pressure	3-138 MPa	3-138 MPa
Temperature	21 °C	21 °C
Force	44 kN	22 kN
Displacement	25 mm	5 mm
Test control	.025-25 mm/s: tensile 1 minute – 1 day : Fracture	0.001-10 Hz



Gas management

High pressure
regulator



To test
vessel

Accumulator
/ replenisher

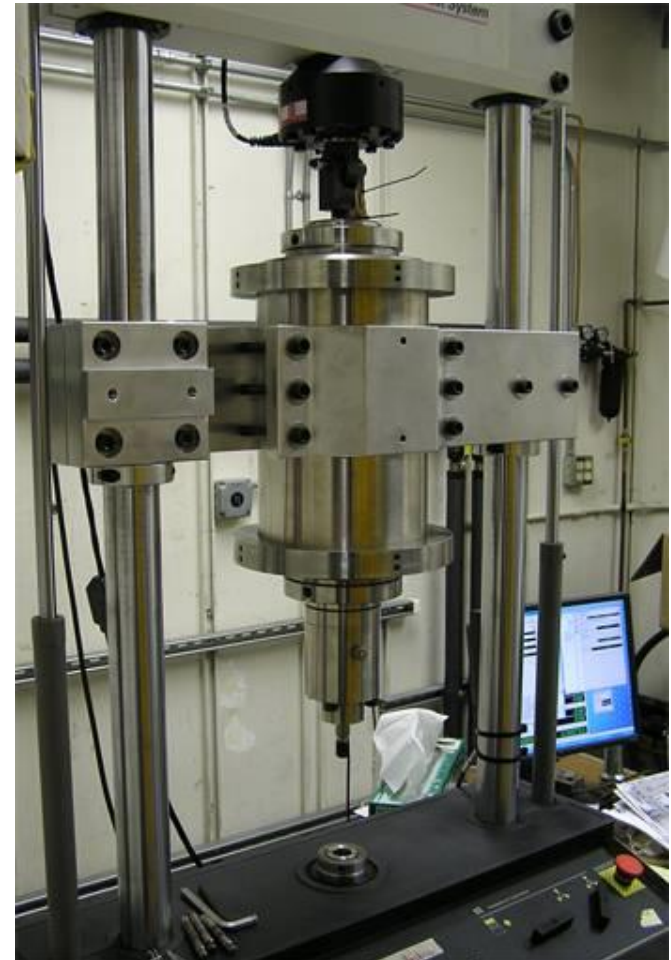
- Manual operation
- Accumulator / replenisher
- High pressure regulator with self-venting feature
- Gas sample station
 - Periodic test gas sampling
 - Gas analysis by outside vendor



Test gas quality control

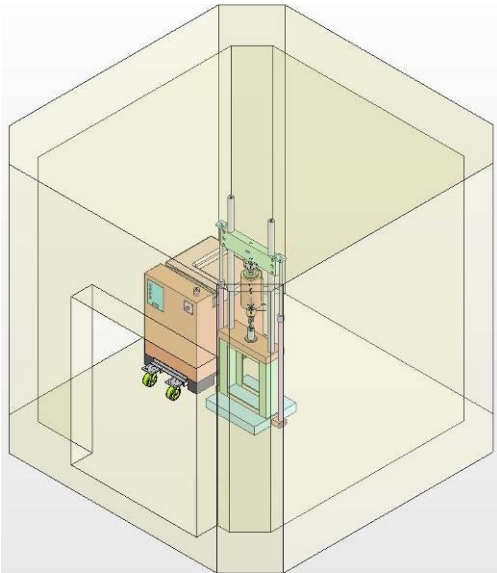
Pressure vessel and manifold purging

- (4) helium purges, 14 MPa
- Vacuum, 20 minutes
 - Vacuum roughing pump
 - 1 to 5 mTorr
- (4) hydrogen purges, 14 MPa
 - 99.9999% pure hydrogen



Safe operations using engineering controls

- Explosion rated test cell
- Exhaust ventilation
- Secondary containment
- H₂ sensors integrated with ventilation
- H₂ supply interlocks
- (Limited H₂ volumes) < LFL
(lower flammable limit)



- ASME rated vessel
BPVC Sect VIII, Div 2
- Material: A286
- Main seal vent ports



Hydrogen compatible material in all wetted components.

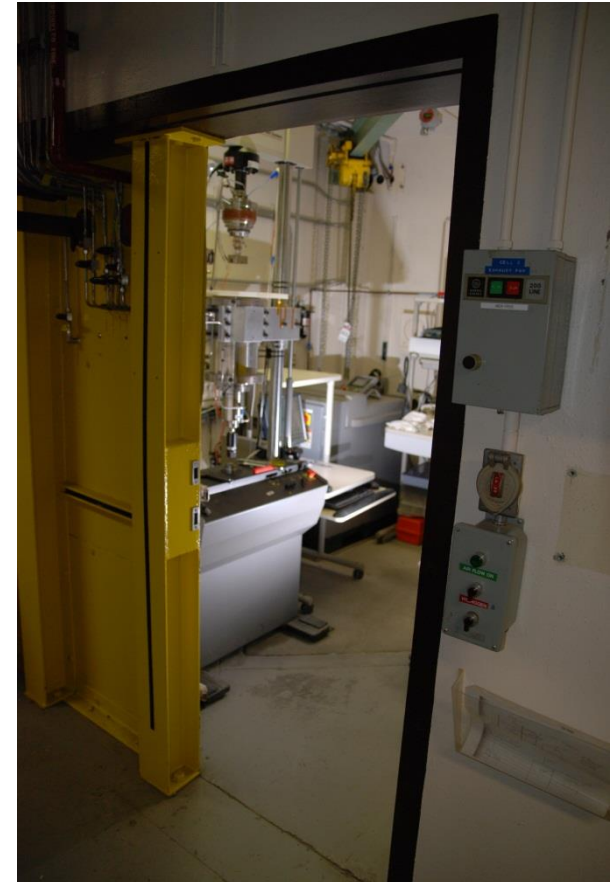


Remote control operations



Safe operations during setup and test using administrative controls

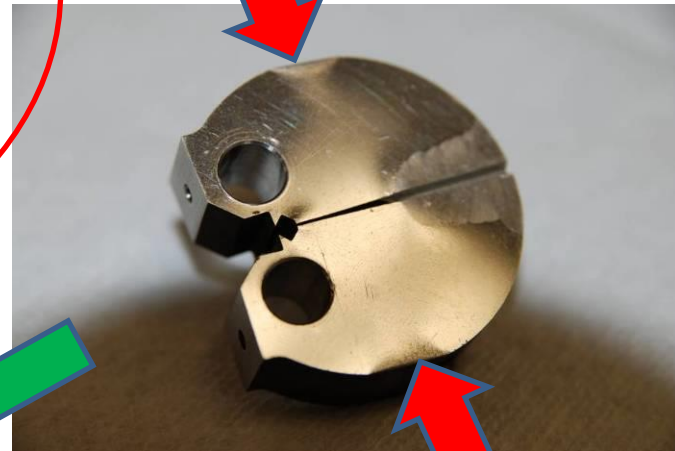
- Education, training, and documentation
- Operational procedures
 - Hydrogen never exposed to air
 - Air/helium/hydrogen/helium/air
- Safe guards
 - Locked test cell
 - Controlled access to laboratory



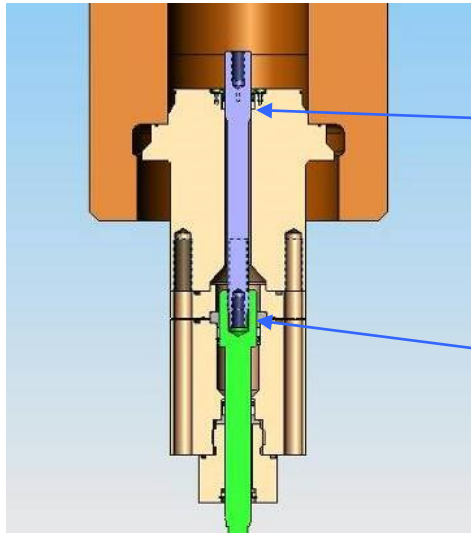
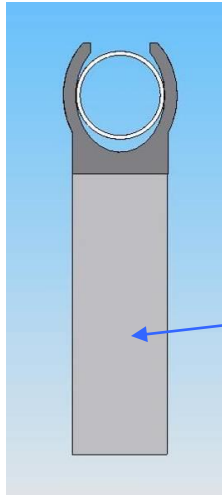
Challenges and successes with test operations

- Test hardware
- Infrastructure hardware
- Gas management
- Test control

When tests go
horribly wrong



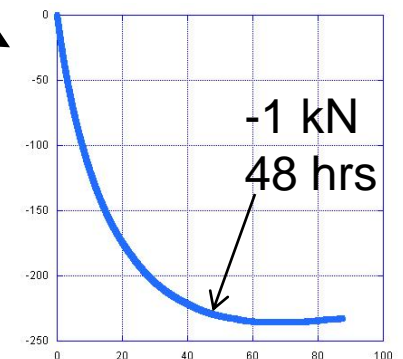
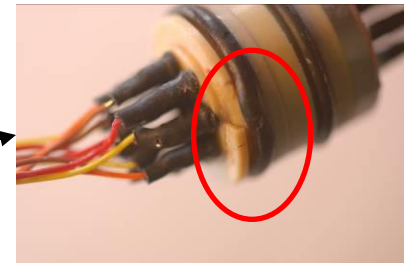
Test hardware



Hardware	Challenge	Solution
Pressure vessel	none	
Dynamic seals	Insufficient product	New vendor
	Collapsing backup ring from new vendor	Change in raw material
	Scratched seal	Change in assembly procedure
	High leak rate	Change in assembly procedure
Pull Rods	Rod to bore galling	Engineered alignment sleeve & carburized rod
	Rod buckling from over-load	Improved test control
	High leak rates Poor test control	Engineered rigid assembly

Test hardware, continue

Hardware	Challenge	Solution
Feed-through connector	Explosive decompression 100-0.1 MPa	Increase decompression time to > 30 minutes.
Static o-rings	Explosive decompression 100-0.1 MPa	Increase decompression time to > 30 minutes.
Load cell	H ₂ induced zero drift	Allow 48 hours to condition load cell
LVDT	None	



Hours

Infrastructure hardware



Hardware

Newport gas
compressor

Challenge

Check valve &
diaphragm failures

Solution

No long term
solution

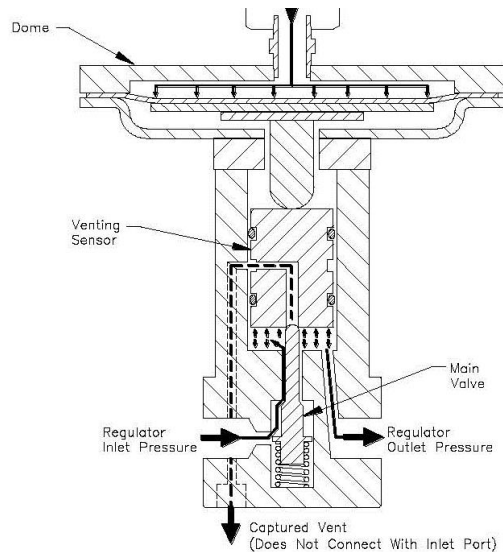
Tescom regulator

Explosive
decompression of
seals

Increase
decompression
time to > 30
minutes.

Poor control using
facility compressed
air

Independent
nitrogen gas supply

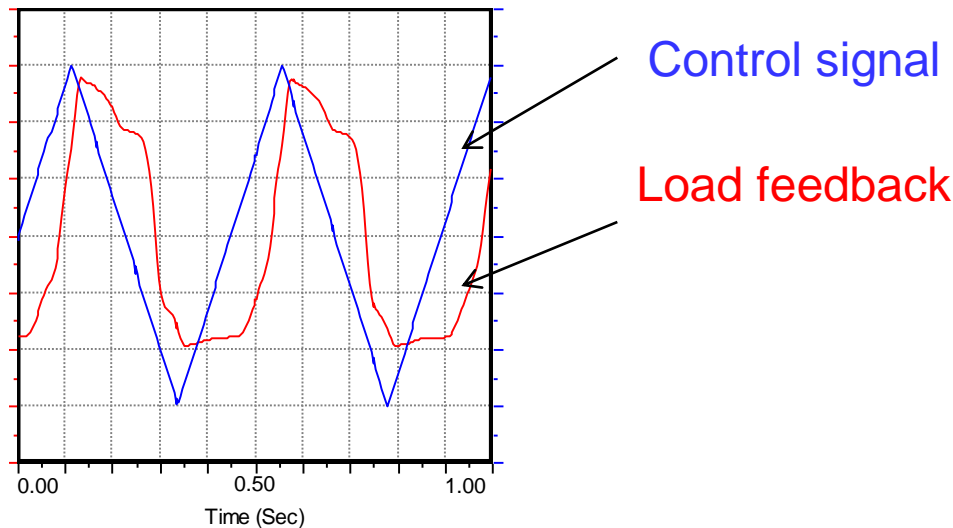


Conducting a test: Who's in control?

Challenges

Pull Rods uncoupling

- Software errors
- Limits applied loads
- Compromise load waveforms



High seal frictional forces, 4.4 kN at 100 MPa

- feed-back control
- Software over-command

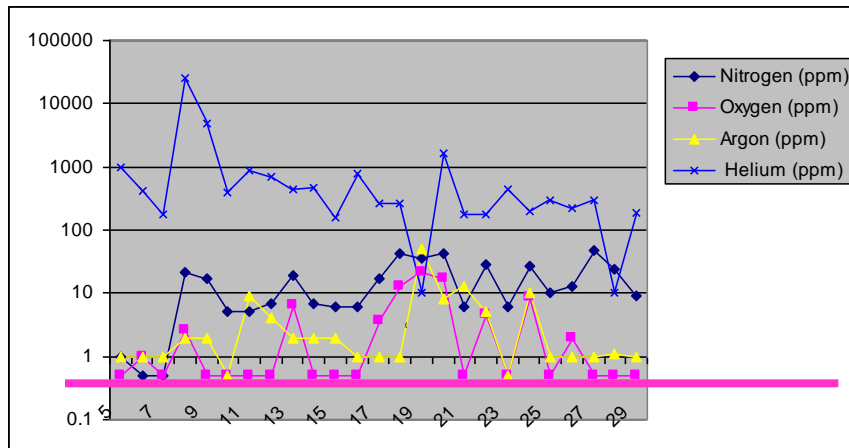
Solutions

- Rigid fixturing
- Test control tuning
 - Seal friction
 - Test pressure
 - Frequency
 - Applied load
 - R-ratio
 - Compliance
 - Specimen material
 - Crack length

Test gas contamination

Challenge

- Inadequate purging



Solution

- Change Procedures
- Frequent gas sampling
- Final test gas
is not 99.9999% pure H₂
- Typical test gas
 - < 0.5 ppm O₂
 - < 3 ppm H₂O

Next generation test capabilities

- Pro
- Au ment
- -10 ms
- (2



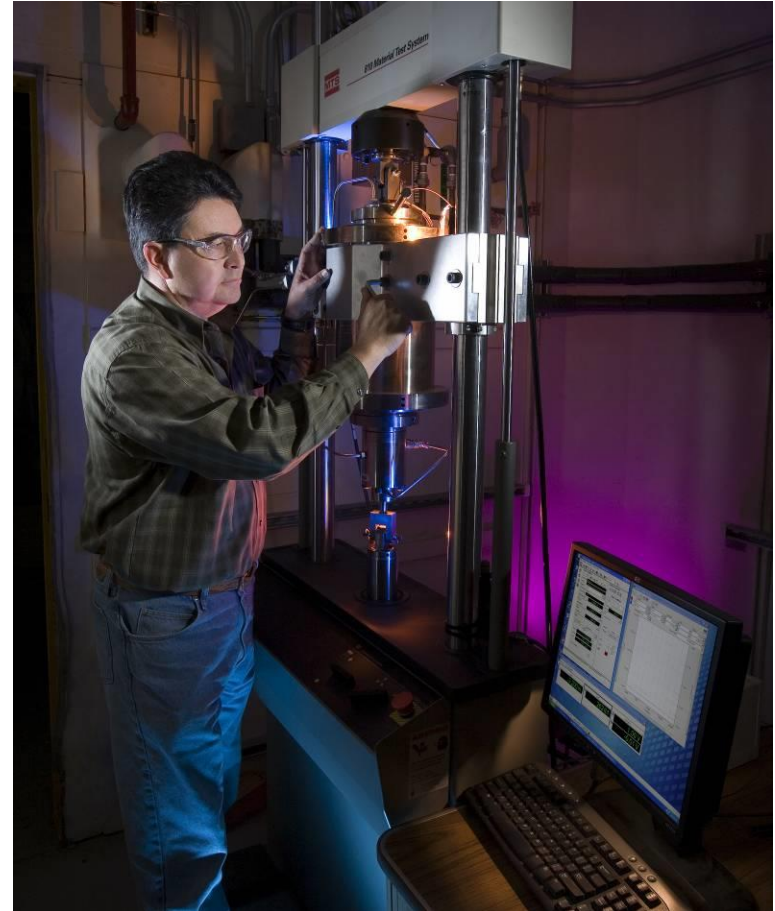
Current



Next

Conclusion

- **Advantages**
 - High pressure
 - 138 MPa
 - Large frequency range
 - .001-10 Hz
 - Small vessel
 - Fits hydraulic test frames
- **Disadvantages**
 - Initial operational issues
 - High gas leak rate
 - Test control issues
- **Enduring challenges**
 - High pressure compressor
 - Diaphragm failures
 - Check Valve failures
 - Load cell transducer
 - Hydrogen effect on strain gages



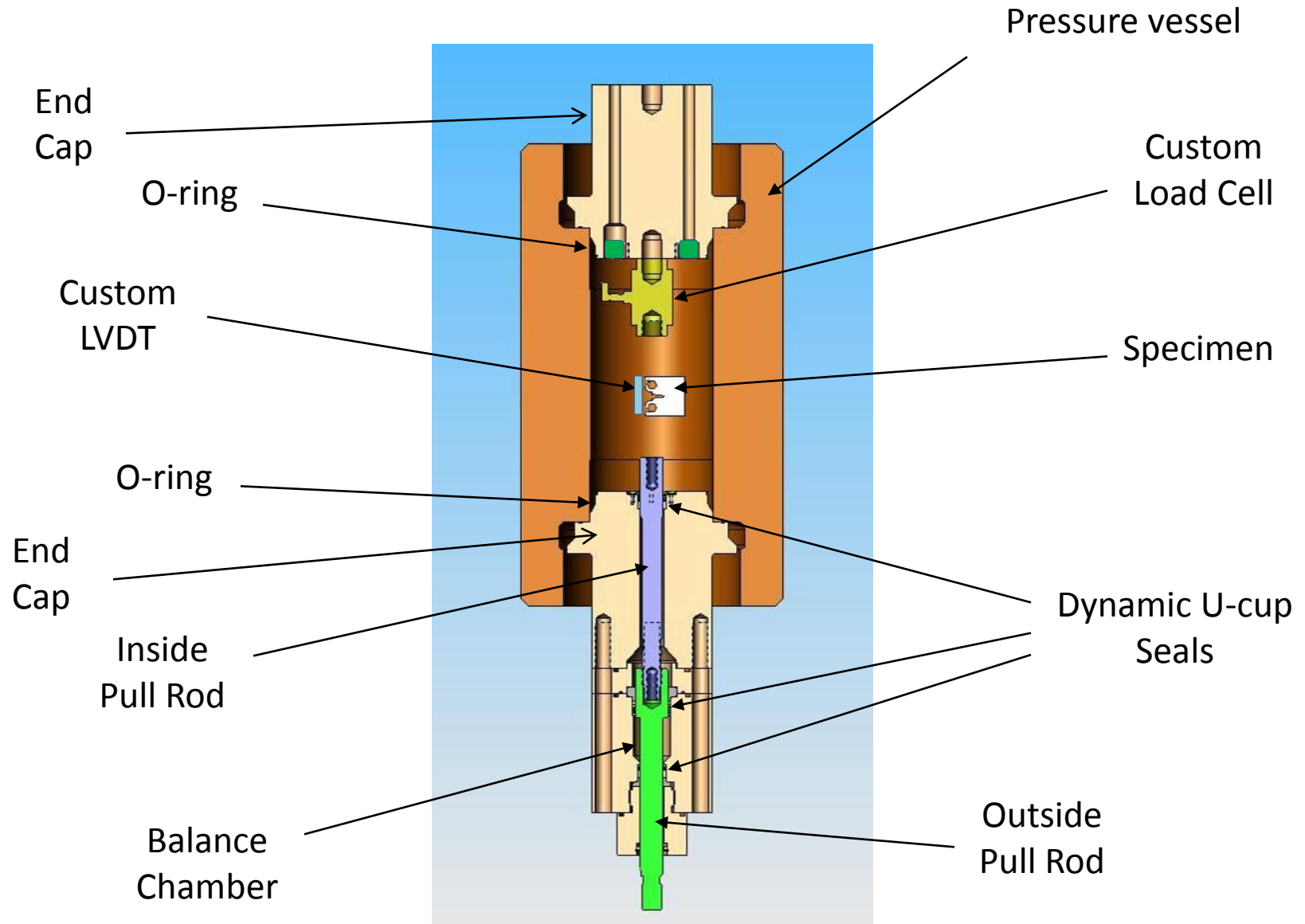
Acknowledgements

- The ongoing support from the US Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Program is gratefully acknowledged.
- This capability is made possible by Hydrogen Effects on Materials team at Sandia National Laboratories in Livermore CA:

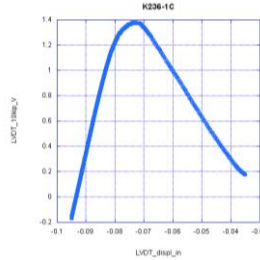
Dr. Brian Somerday
Dr. Chris San Marchi
Ken Lee
Jeff Campbell

Dr. Kevin Nibur
David Zanini
Ken Stewart
Mark Zimmerman

Thank You



Conducting a test



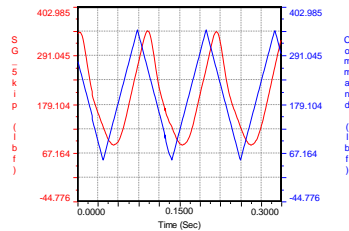
Tensile/fracture

Software

MTS
Basic TestWare
Station Manager 3.5B

Test method

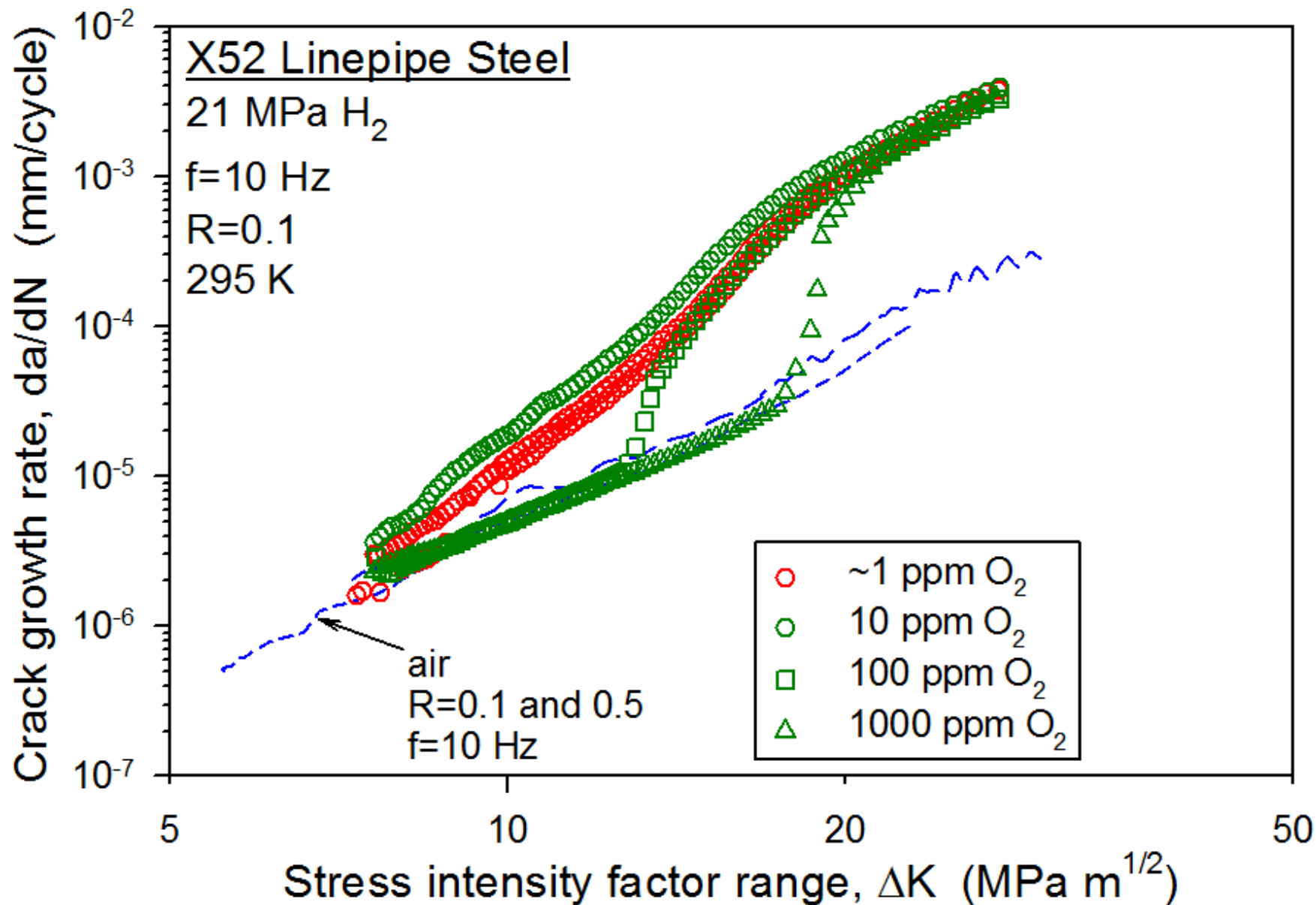
ASTM E1820
fracture

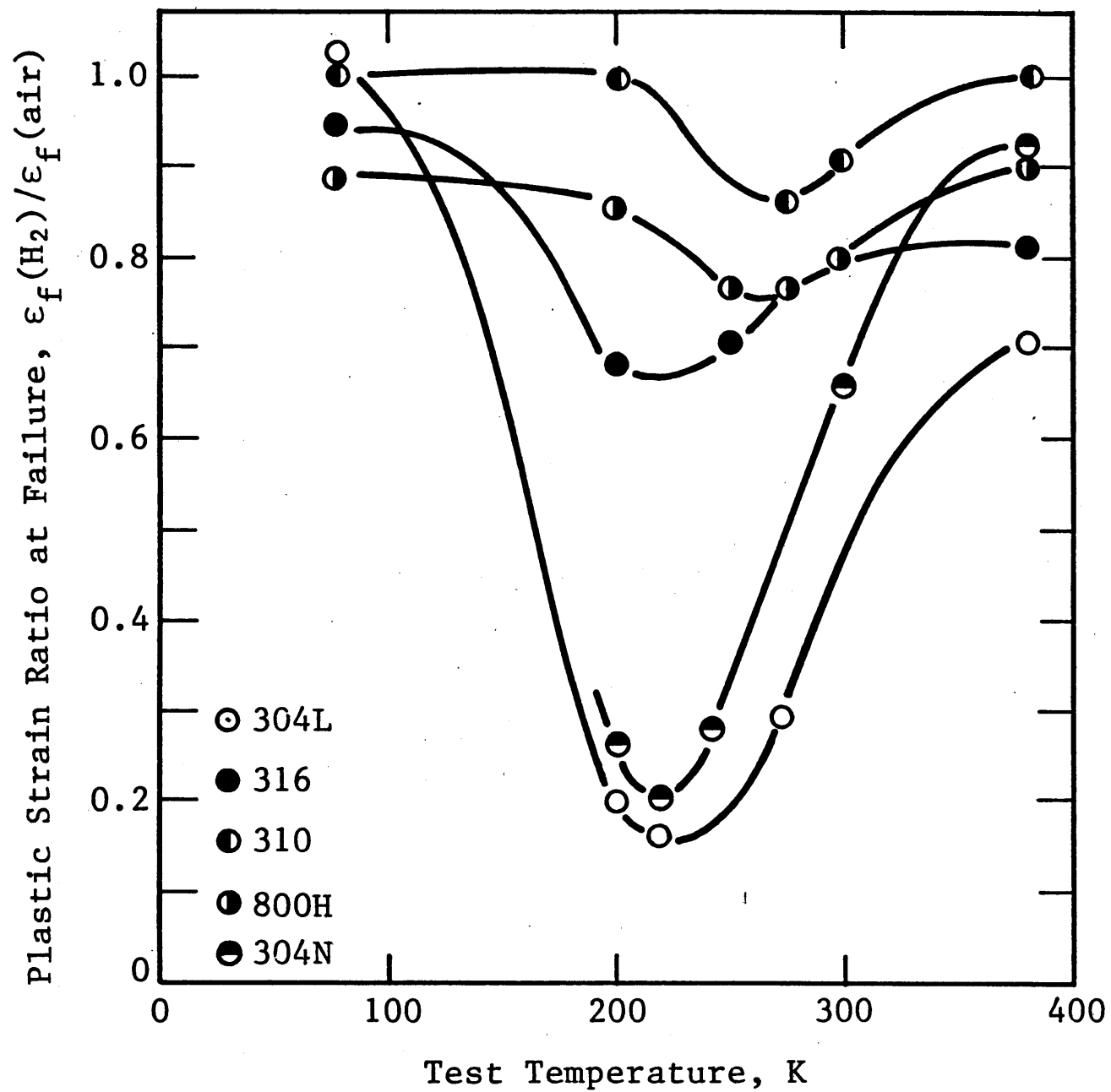


Fatigue

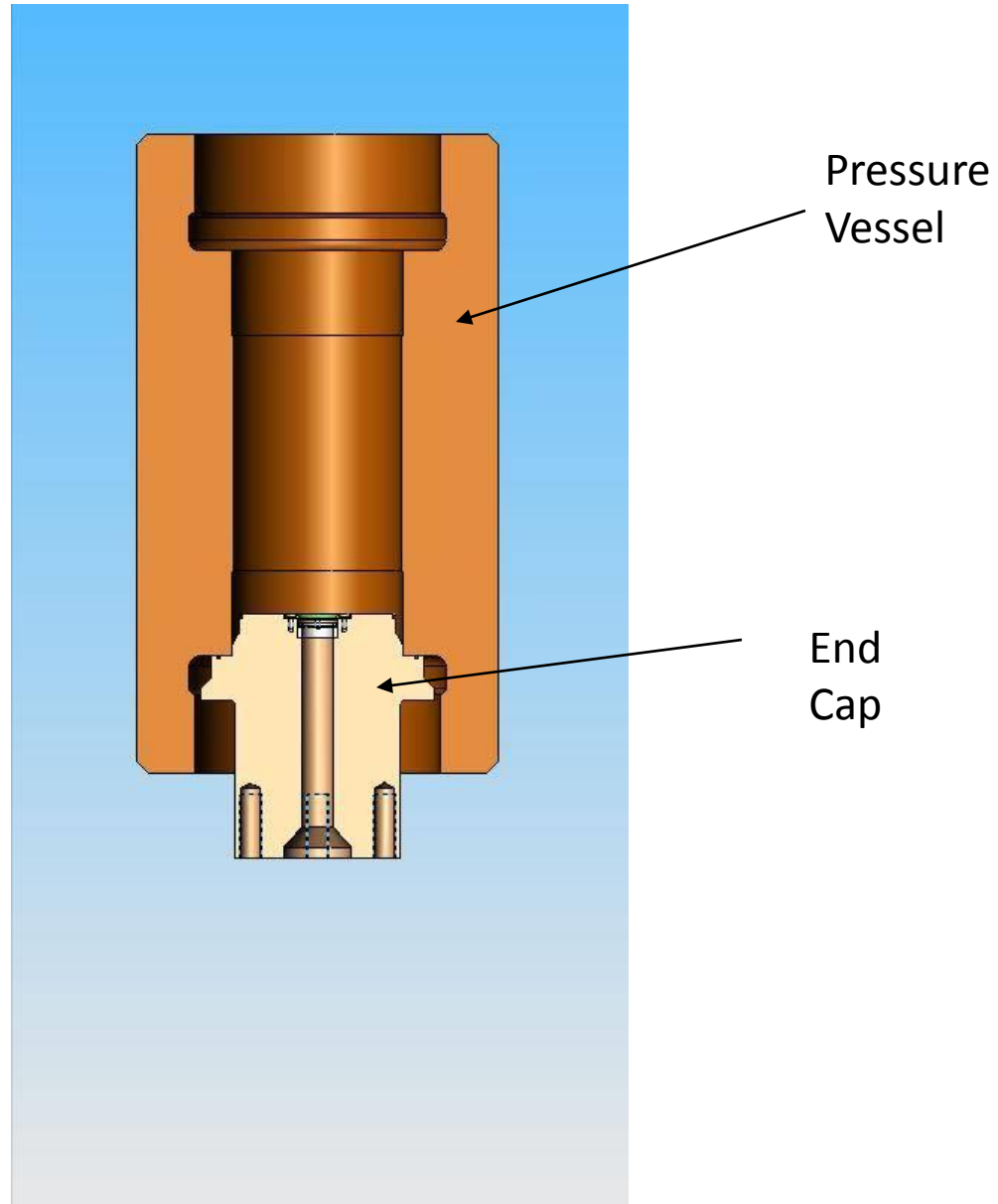
MTS
Fatigue Crack Growth
Version 4.9

ASTM E647

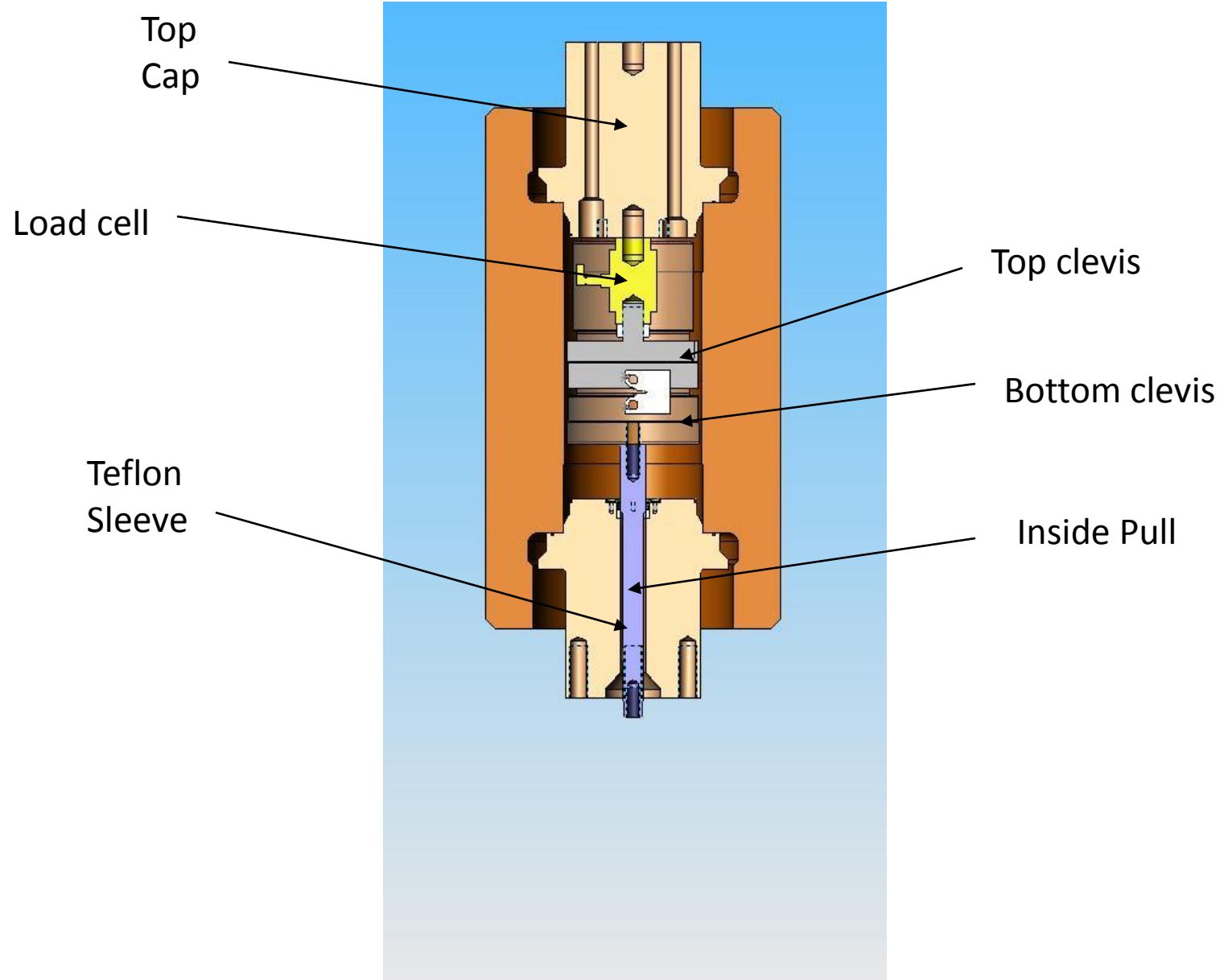




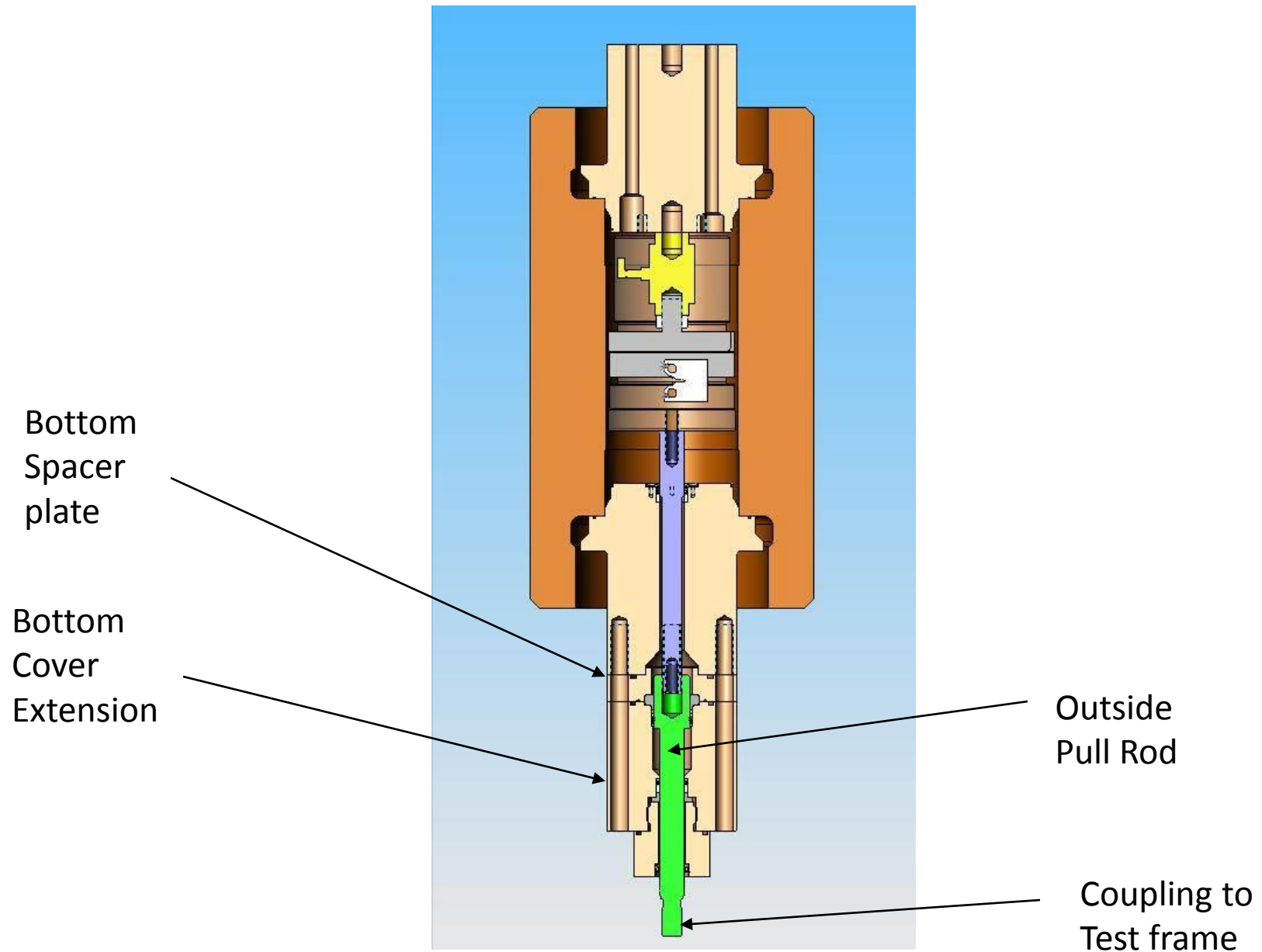
Pressure vessel assembly sequence



Pressure vessel assembly sequence



Pressure vessel assembly sequence



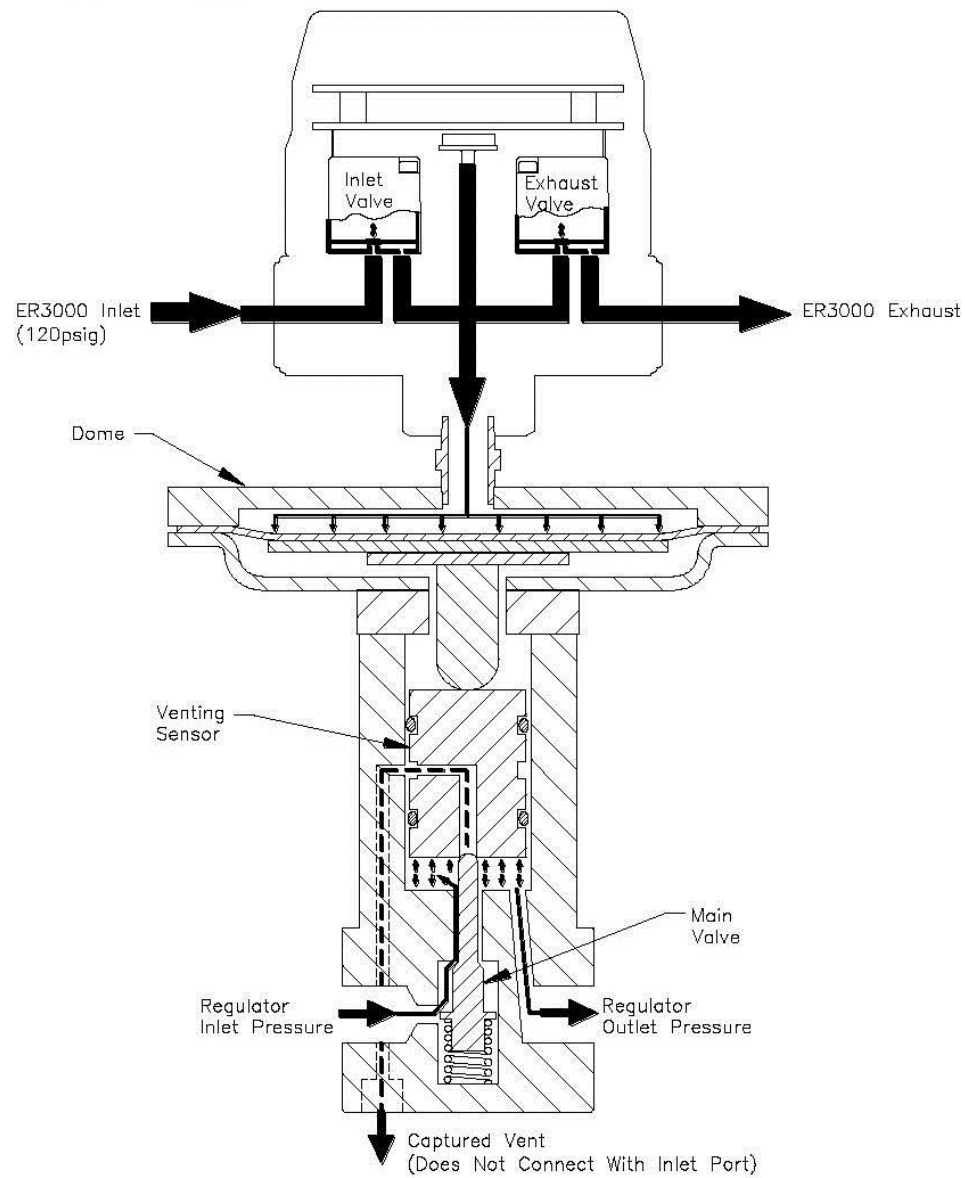


Figure 20: Regulator and ER3000 Internal Operation

